PHYTOREMEDIATION FOR AIR FORCE SITES

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Introduction and definitions

Phytoremediation is a developing technology with good promise. However, success with phytoremediation requires (1) application of a different set of engineering and scientific principles than is employed by previously used technology, and (2) clear understanding of the limits of the new technology.

Phytoremediation is the direct use of living plants for remediation of contaminated soil, sludges, sediments, or groundwater through contaminant removal, degradation, or containment of the contaminant(s). Growing and, in some cases, harvesting plants on a contaminated site as a remediation method is an aesthetically pleasing, solar-energy driven, passive technique that can be used to remediate sites with shallow, low to moderate levels of contamination. This technique can be used along with or, in some cases, in place of mechanical cleanup methods.

The concept of phytoremediation is not new; plants naturally consume and recycle materials that otherwise would become contaminants. For example, plant organisms consume oil naturally discharged into the ocean, wetland plants remove contaminants from river and estuary systems, and plants consume the nutrients produced by decaying wild animal waste and rotting trees and grass. The deliberate use of phytoremediation to remove contaminants from water and soil in a controlled situation is a new technology.

Phytoremediation can be used to remediate metals, pesticides, solvents, explosives, crude oil, polycyclic aromatic hydrocarbons, and landfill leachates. Plants can serve as hydraulic pumps when their roots reach sufficient depth where capillary action can draw moisture from the water table. For example, a large tree can transpire up to 300 gallons of water per day from the water table under favorable conditions. Groundwater extraction by phreatophytes can provide effective hydraulic control of contaminated subsurface water under selected conditions.

Phytoremediation is a general term applied to the use of plants to remediate contaminated sites; however, there are substantial differences in the way the technology could be used to remediate different sites. The contaminant(s) and local conditions determine the appropriate sub-field of phytoremediation for a particular site.

The definitions below generally follow those used by the US EPA (1999). The prefix *phyto* means *plant* or *to grow*. The prefix *rhizo* means *root* and in the context of phytoremediation includes *contact with plant roots*. The sub-fields of phytoremediation may be defined as follows:

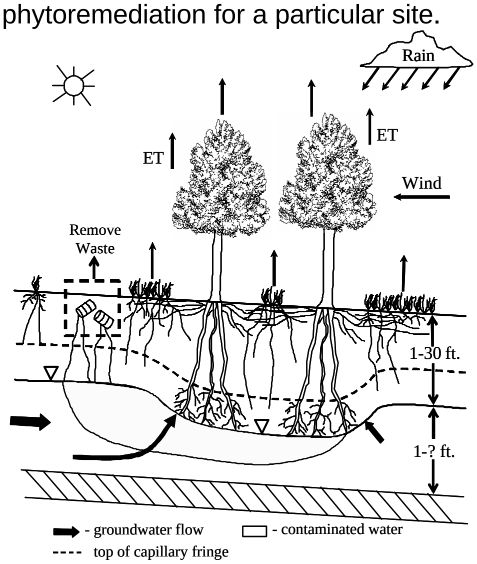

Figure 1 Phytostabilization site

- **Phytostabilization** is the use of plants to immobilize contaminants in the soil and/or groundwater by (1) removing groundwater from the capillary fringe at a rate sufficient to stabilize movement of near-surface groundwater or (2) by accumulation by roots, adsorption on the surface of roots, and precipitation of chemicals within the root zone. One form of phytostabilization is depicted in Figure 1.
- **Phytoextraction**, also called phytoaccumulation, refers to the uptake by plant roots of contaminants from the soil or soil water and translocation into plant parts, preferably aboveground portions of the plant. The plants are harvested and disposed in a manner appropriate for the accumulated contaminant(s).
- **Rhizofiltration** is the adsorption or precipitation onto plant roots or absorption into the roots of contaminants that are in the solution surrounding the roots. The plants used for cleanup are grown in hydroponic culture in greenhouses or a similar system where their roots are grown in the contaminated water and not in soil. In this case, the water is brought to the plant.
- **Phytodegradation**, also called phytotransformation, is the breakdown of contaminants taken up by plants

through metabolic processes within the plant, or the breakdown of contaminants external to the plant through the effect of compounds (such as enzymes) produced by the plants. Contaminants are degraded, and may be incorporated into the plant tissues, or used as nutrients.

- **Rhizodegradation** is also called enhanced rhizosphere biodegradation, phytostimulation, or plant-assisted bioremediation/degradation. It is the breakdown of contaminants within the soil through microbial activity that is enhanced by the growth of yeast, fungi, or bacteria on the natural substances released into the soil by plant roots—sugars, alcohols, and acids—containing organic carbon. The organic carbon provides food for soil microorganisms which biodegrade contaminants as they consume the plant root exudates.
- **Phytovolatilization** is the uptake by plants of contaminants that are, in turn, released from the plant in vapor form into the atmosphere. The contaminant may be modified chemically within the plant before release into the atmosphere.

Phytoremediation is a relatively new application of naturally occurring biological processes to environmental remediation. Because of its widespread and favorable reception by the public, technical community, and regulators, it is being employed at numerous sites. Regulatory acceptance is likely easier to gain for phytoremediation than for other new technologies; nevertheless, every proposed use will require careful justification to the regulatory bodies and the public.

As an emerging technology, guidance documents for the application of phytoremediation are just becoming available and include the AFCEE sponsored work by Hauser et al. (2001), and publications by ITRC (2001), and US EPA (1999 & 2000).

Technology Issues

Phytoremediation is based on plant growth; therefore, it employs a complex system. Numerous interacting factors must be considered during planning, design, and operation of phytoremediation systems. Fields of knowledge required include: agricultural engineering, soils, agronomy, hydrology, chemistry, and others as needed for problems that arise.

Phytoremediation is effective for contaminants contained within the plant root zone. The depth of the plant root zone depends on plant, soil, and climate factors.

Climate will control the selection of plant species employed and how well they function at a site. Climatic factors important to plant growth include: solar radiation, air temperature, precipitation (amount and distribution during the growing season), dew point (or the more commonly reported relative humidity), wind, and the length of the growing season. Day length may be important for some plants.

Properties of plants and how they grow combine to define plant factors which are important to success. Important factors include: climate required by the plant, growth rate, size of the plant (biomass), root distribution patterns within the rhizosphere, whether the plant has tap roots or fibrous root system, and root density in each soil layer. Figure 2 illustrates the possible adverse impact on root growth of high strength soils that are caused by high soil density. High soil density inhibits root growth.

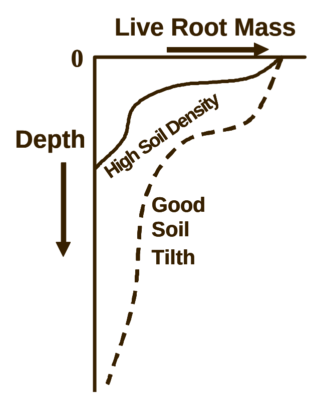

Figure 2 Distribution of roots in high or low density soils.

The properties of soils may be highly variable and should be carefully evaluated before undertaking phytoremediation at each potential site. Soil properties that affect root and plant growth include: pH, plant nutrient status, humus content of the soil, salinity, and soil strength. The soil must be free of chemicals that may be toxic to the plants grown.

Where soil properties are undesirable, organic material may be added to improve them. While the organic material may improve soils in the short term, the soils are likely to revert to their original condition before the end of the phytoremediation project. Humus (also called soil organic matter) is composed of stable, natural organic compounds. Humus is an important component of soils; it aids in establishing good soil tilth, increases soil water holding capacity, increases the cation exchange capacity, and benefits plant growth. However, soils low in humus may also be fertile and very productive, e.g. soils of the southern Great Plains and irrigated deserts of the western states. Humus should not be confused with “organic materials” that may be added to soils. Compost, sewage sludge, manure, hay, straw, leaves, and other material are organic materials and may be added to the soil to improve its properties; however, they are not humus. Humus is stable organic material generated very slowly within soils over centuries. Organic material added to improve soil properties will decay rapidly (months or a few years) and little or none will become humus. Organic material added to the soil to improve its properties may remain active for a few months or at best a few years, and then the soil reverts to its original condition.

Soil strength is important because roots grow poorly or not at all in soils of high strength. Normal activities at Air Force bases may seriously damage soils by increasing the soil strength sufficiently to inhibit plant root growth. Soil strength is controlled by several factors, including soil density, water content, and particle size distribution. Soil density can often be controlled or modified. In all cases it should be evaluated for its influence on possible success of a phytoremediation effort. If soil density is favorable, the other factors controlling soil strength have much less impact on plant growth. Generally soil bulk density should be less than 1.5 Mg/M^3 for sandy soils and less than 1.4 Mg/M^3 for clay soils.

Several cultural factors are important to success of the phytoremediation effort. Machines should be readily available to perform the following functions: plant, harvest, process (if needed), and establish transplants (if needed). Especially in arid or semi-arid climates, irrigation may be required.

Summary

If correctly applied, phytoremediation is often successful. Important advantages and disadvantages that should be considered before selection of phytoremediation technology include:

Advantages	Disadvantages
• Solar energy driven	• Requires large land areas
• Natural	• A slow process
• Self sustaining	• May require soil treatment
• Effective	• May require relocation of other work
• Low cost	
• Useful for final cleanup of low concentrations of contaminants	

Phytoremediation requires new engineering and scientific expertise; however, it has good potential for use by the Air Force.

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